The TREND IN ENGINEERING

at the University of Washington

In this issue:

USE OF WASHINGTON BENTONITE AS A HYDRO-SEAL

A ROTATION INDICATOR FOR PLASTIC BENDING TESTS

VACUUM METALLURGY

EARTHQUAKE INVESTIGATION AT THE UNIVERSITY OF WASHINGTON

October, 1956

Published quarterly by

THE ENGINEERING EXPERIMENT STATION

THE FORMULATION OF PROBLEMS IN RESEARCH*

RESEARCH HAS MANY ASPECTS, and it appears differently to different people. The number of those who talk and write about it is increasing much faster than the number of those actually engaged in it . . . While it is reasonable to assume that the only people who know what research is about are those who have actually been engaged in it, there is no denying that the influence on our society of those who talk and write about research is much wider than the influence of those who do it.

This is not a new phenomenon. Francis Bacon, who did not amount to much as a scientist, established himself by his writings about science ("Novum Organum") as the recognized spokesman of the utilitarian philosophy of science, a viewpoint that has grown like a snowball in the last three centuries. The doctrine of social utility as the only aim of science and research has gained official acceptance in Soviet Russia; but we should also recognize that in our own country both industry and government are strongly influenced by this doctrine, more strongly, in fact, than we usually care to admit. Contrary to the European tradition, this utilitarian doctrine is not tempered by any inherent respect for learning as such. In fact, many of our industrial and military research administrators would probably be surprised to discover that there can be any other philosophy, that motives different from that of "utility" may influence men to choose research as a career, and that neither Archimedes nor Newton were influenced by this motive. When the protagonists of the utilitarian doctrine claim that even Leonardo da Vinci in his famous letter to the Duke of Milan offered his technological skill, this only shows that Leonardo's times were not so different from our own. Leonardo was aware that "sponsorship" was more easily available for technology, particularly military technology, than for research for its own sake; it does not mean that Leonardo was motivated to invent his different war-machines by their utility. They were the by-products of his interest in mechanics. Like Newton, he was driven by a somewhat mystical desire to understand for the sake of understanding. Archimedes, on the other hand, like Einstein and many of the modern mathematicians and theoretical physicists, was driven by the strongly aesthetic motive of creating order by clear logical thought, a motive closely related to that driving the artist.

Aesthete, mystic, utilitarian. These are the three faces of the scientific research worker; he may have all three of them or only one. His motivation will usually be a mixture of the three basic moving forces . . .

Motivation in scientific work is very closely related to the question of problem formulation. It is quite obvious that different primary motivation will lead to different ways of choosing and formulating a problem. The utilitarian, for example, will usually have a definite goal to achieve and thus be mainly concerned with the means of achieving it. His mind goes from the goal to the means, from the question to the solution. The aesthete or the mystic may discover a phenomenon, a fact, or a formal rule, imagining afterwards what it could be useful for. His mind goes from the means to the goal, the answer appearing in fact before the question.

Paradoxical as this may seem, the second kind of approach is not only the more general, but the more fruitful. This becomes increasingly apparent as science advances. It is almost an axiom that in scientific work (as distinguished from industrial development work) practical application is found by not looking for it. But application is important since it opens new questions. Most of the important discoveries appeared to have no practical application at the time they were made, however. This is as true with respect to the form of the ellipse discovered by the Greeks, but only used by Kepler for "practical" purposes 2000 years later, as it is with respect to atomic fission.

One of the most serious deficiencies in the organization of research in our society is that this principle is not recognized. Some of the minds responsible for administrating research funds seem unable to grasp the fact that practical questions are usually solved by means of existing theories, while practical applications of purely scientific discoveries are generally rather remote in time . . .

Problem formulation depends significantly on administration and organization of research. In this respect the methods developed by industry and government have reached a high degree of efficiency in discouraging original and fundamental research work, while encouraging second-rate derivative "research." One reason for this is the mistaken belief that the research administrator should be made to understand both purpose and method of the research he is supporting before such work is approved.

Another reason is the belief that effective research must be "planned," "targets" and "target-dates" set and met, "research teams" assembled on the basis of "group adjustment," in short, that research is a commodity for which a manufacturing process can be set up, the product being research reports. In this atmosphere problems are not selected and formulated on their merits or on the basis of the personal interest of the investigator in the problem. . . .

While research must be "administrated," just as any other activity that has reached a certain level of complexity, administration by people who have had no first-hand experience in research but still insist on making research-policy decisions (including formulation of problems) will seriously undermine research activities. Problem formulation is the most important part of a research; only the experienced research worker knows that all successful research is essentially a guessing game in which you not only try to guess at the answer before solving the problem, but possibly even before completely formulating it. And such guessing presupposes a considerable familiarity with the particular sphere of research involved. In fact, once you know enough about the problem to formulate it adequately, you must already have a good qualitative guess at the answer. . . .

The formulation of an engineering or industrial problem differs from that of a physical problem by the larger number of abstractions required to transform reality into a manageable model and by the additional specification of the purpose in operational or economic terms. The relevance of the purpose delimits, in fact, "basic" or "applied" research, and distinguishes the engineering from the physical sciences. The formulation of the problem and thus its solution is strongly dependent on the specified purpose; solutions are obviously no longer unique. Moreover, they usually refer to an oversimplified model obtained from reality by a considerable number of abstractions. They are therefore subject to a rather wide margin of uncertainty. It is this uncertainty which necessitates the

(Continued on page 24)

* From a talk by Dr. Alfred M. Freudenthal, Professor of Civil Engineering (Columbia University), at the Seventh Annual Conference on Industrial Research, sponsored by the Department of Industrial and Management Engineering of Columbia University, June 11-15, 1956, and appearing in the July issue of *Research and Engineering*.

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

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(2) to undertake extended research and to publish reports on engineering and scientific problems;

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2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
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October, 1956 The TREND

IN ENGINEERING

Vol. 8 No. 4

Published quarterly in January, April, July and October, by the Engineering Experiment Station at the University of Washington to reflect the current highlights of its accomplishments and to report progress in its program of investigation and research.

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127 More Hall
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Entered as second-class matter March 7, 1949, at the post office at Seattle, Washington, under the Act of August 24, 1912.

at the University of Washington

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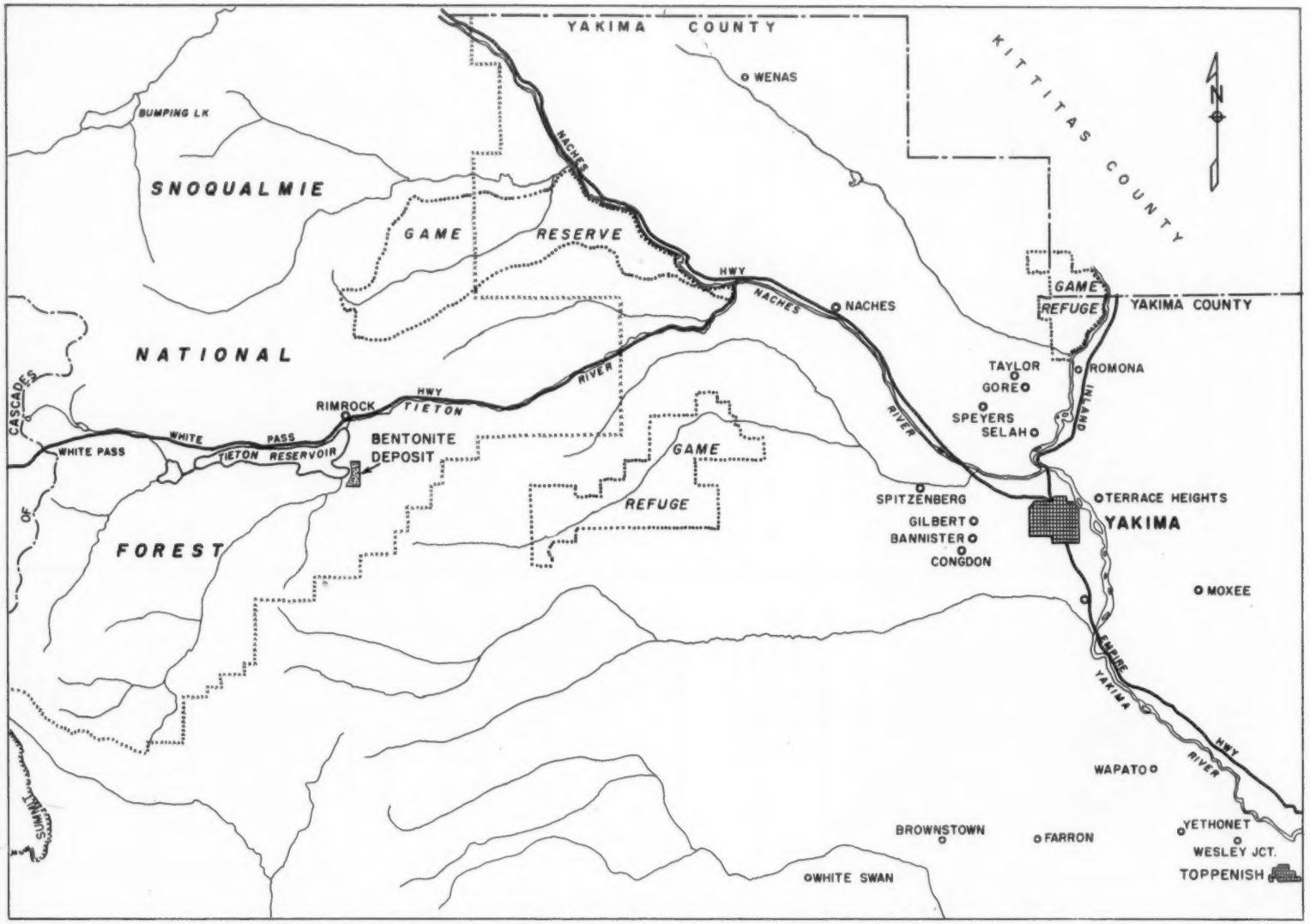

MAP SHOWING LOCATION OF BENTONITE OCCURRENCE NEAR THE TIETON RESERVOIR IN YAKIMA COUNTY

USE OF WASHINGTON BENTONITE AS A HYDRO-SEAL

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Introduction

The unusual versatility of bentonite in meeting varied industrial demands has been recognized for many years. It is used for oil-well and other drilling fluids, as a bond for foundry sands, as a bleaching and decolorizing agent for oils, as a plasticizer (a bond in briquetting), as thermal, electrical, and accoustical insulation, and as a coagulator and suspending agent. In addition, it has been used for many years as a sealing agent to prevent leaks in dams, foundations, and other structures designed to contain water. The wide diversity of use is matched by an equal or greater difference in the quality of natural bentonite deposit. Not all bentonites have commercial value, and none is satisfactory for all uses. The diversity of character is due in part to a wide variation in composition and type of the clay-mineral constituent and in part to the proportion of one clay mineral, montmorillonite, to the nonclay fraction.

Because of the broad industrial use of this type of clay, the Bureau of Mines investigated the bentonite occurrences within economical shipping distance of the metropolitan areas of Seattle, Tacoma, and Portland. During this investigation, one deposit near the Tieton Reservoir, Yakima County, Washington, appeared to have unusual qualities as a sealing agent. Although the laboratory testing of the bentonite samples follows conventional methods, which do not include determination of the sealing capacity, some of the tests were interpreted as indicating the presence of this quality in the Tieton material. The extensive development of irrigation projects in new farm lands in eastern Washington and the necessary distribution and consequent loss of water through walls of canals and ditches prompted further testing of the bentonite to measure its capacity to seal porous beds. High capacity to seal porous beds would effectively reduce the loss of water by leakage. Laboratory testing indicated that, if properly applied, bentonite from the Tieton area could materially aid in conserving irrigation water. Moreover, if the water was retained in the proper channels, it would not appear in areas where its presence could be detrimental.

H. M. Harris

K. G. Strandberg

This report relates laboratory testing done to indicate the capacity of the Tieton bentonite to function as a hydro-seal as compared with a bentonite generally accepted as a commercial standard for this purpose.

Mineralogy of Bentonite

Bentonite is formed by the weathering and alteration of volcanic rocks to form a clay mineral, montmorillonite, and minor residual minerals such as felspar, quartz, calcium carbonate, gypsum, and glass. Thus, bentonite is a rock composed largely of the clay minerals of the montmorillonite group. This mineral group is composed of five or more specific minerals having an infinite number of chemical compositions between the five end members of the series. The chemical formula for the montmorillonite group may be expressed as $Al_2O_3.4SiO_2.\ xH_2O$; iron and magnesia may replace some of the alumina and occasionally some of the silica. The mineral montmorillonite, a member of the mineral group of the same name, is one in which all or most of the replaceable alumina has been replaced by magnesia. If ferric iron replaces most of the alumina, the mineral is nontronite. When silica is replaced by alumina so that the ratio of Si to Al is 1 : 8, the mineral is beidellite. Total replacement of alumina by magnesia yields the mineral saponite. When Si^{++++} is replaced by Al^{+++} or Al^{+++} is replaced by MgO^{++} or Fe^{+++}, an unbalance of charge exists on the montmorillonite lattice. The replacements mentioned may be complete or only partial; thus, a series of chemical

compositions exist for each mineral and variable charge deficiency. These charge deficiencies are balanced in part or totally by exchangeable cations between the layers of the montmorillonite lattice and, in less quantity, on the lattice edges. The montmorillonite lattice is a three-layer type; that is, an alumina layer is sandwiched between two silica layers. The character of the interlayer ions strongly influences the physical qualities of the montmorillonite mineral.

For commercial uses bentonites may be classed as swelling and nonswelling. The swelling type displays a lattice expansion, or an increase in the space between the silica layers and the alumina layer in the presence of water. The spacing between the layers is influenced by the size and character of the exchangeable cation. For a sodium montmorillonite normal spacing is 12.5Å, with 1 molecule of water in the interlayer position. For calcium montmorillonite 2 water molecules are normal, and the spacing is 15.5Å. In the presence of an abundance of water the silica sheets may separate completely from the alumina layer of the sodium montmorillonite, but with calcium montmorillonite complete separation does not occur. Thus, the term "nonswelling" bentonite is only relative, as all bentonites swell to greater or lesser extent in the presence of water. The factor that controls the amount of swelling is the valence of the exchangeable cation. In the best swelling bentonites, such as those from South Dakota and Wyoming, sodium, a monovalent ion, is in the exchange positions. A number of other cations are found in the exchange positions of naturally occurring bentonites, but calcium is the most common. As this is a divalent ion, it creates a stronger bond between the alumina and silica layers and thus decreases the amount of water that can penetrate between the layers of the lattice.

Since the most widely used bentonite is the swelling type and since swelling is controlled by the exchangeable cation, the question arises, "Why not exchange the cation in the nonswelling variety for some monovalent ion, such as sodium?" This exchange has been accomplished in the laboratory, but as soon as the synthetic bentonite is placed in an environment of divalent ions the laboratory ion exchange is reversed. Swelling of the so-called nonswelling bentonites is improved, however, if the environment can be controlled during the process in which the bentonite is being used.

Tieton Bentonite Deposit

The deposit is east of the Tieton Reservoir in E.1/2, sec. 7, T. 13, R. 14 E., Yakima County. The low, rolling hills rising east of the reservoir are overlain by bentonite. Surface flows of bentonite have moved summer cottages and completely destroyed others. The movement has also obscured surface relationship of the bentonite and associated rocks. The bentonite is best exposed about a mile east of the road that traverses the southern shores of Tieton Lake. Exposures of bentonite are found in drainage channels, prospect holes, and surface clefts that have formed as a result of drying and cracking. Earth slides along the road for several miles also disclose bentonite. The apparent source rock is a tuffaceous material that grades into a tuffaceous sedimentary bed. Alteration of the tuff varies from place to place, and the degree of alteration is apparent from the "feel" of the clay. The incompletely altered samples are gritty, while those completely altered have an unctuous feel with no evident grit. The light-colored bentonites, the gray or shades of yellow to yellow-green, usually have greater swelling capacities than the darker shades, which range from dark chocolate brown to black.

Mineralogy

Bentonite from the Tieton deposit is a mixture of three-layered lattice minerals, but exact identification of the constituents is difficult. Sodium montmorillonite, beidellite, and probably other calcium-type montmorillonite-group minerals are present, as well as unaltered tuffaceous material and volcanic glass. Electron micrographs of two samples of Tieton bentonite are shown in Figs. 1 and 2. The filmy material in the lower left corner of Fig. 1 is characteristic of sodium montmorillonite, while the darker, opaque, more crystalline material is the nonswelling type. The unaltered glass shows as long, narrow, sharply angular pieces displaying conchoidal fracture. Nontronite has been indicated by other means of identification; it is probably the thin, tubular-shaped particles. Figure 2 shows a sample having lower swelling capacity than that in Fig. 1. This sample contains less of the filmy material and more of the distinct shapes.

Testing of Bentonite

The large variety of types of bentonite and the diversity of uses have resulted in the establishment of test specifications for only a few individual uses. The American Foundrymens' Association has developed tests for its use, and the American Petroleum Institute has specified procedures to evaluate bentonite for use in drilling fluid or as a bleaching agent. The tests for drilling-mud use include determinations of viscosity, gel strength, filter rate, and wall-building capacity. The grit content and swelling are also measured to assist in evaluation. The filter rate and wall-building tests indicated that the Tieton bentonite might be useful as a sealing agent. Since no tests for this specific purpose had been established, two methods were developed in the laboratory for determining this characteristic.

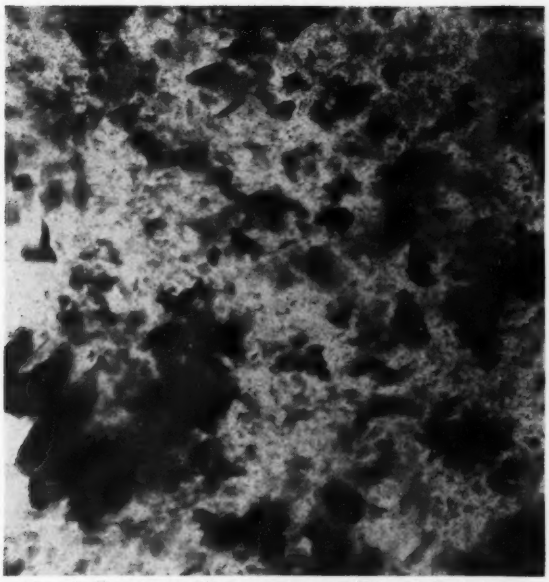

FIG. 1. ELECTRON MICROGRAPH OF TIETON BENTONITE: SAMPLE 1 (Approximately 3000×)

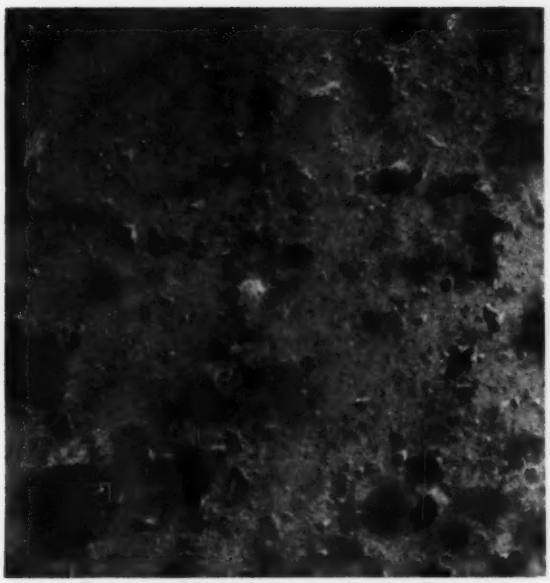

FIG. 2. ELECTRON MICROGRAPH OF TIETON BENTONITE: SAMPLE 2 (Approximately 3000×)

Chemical Analyses

The chemical analysis of bentonite, unless complete, is of restricted value. Nevertheless, even an incomplete analysis has some value. Two samples of Tieton bentonite having widely different viscosity values (shown in the electron micrographs of Figs. 1 and 2) have been analyzed. These data are presented in Table I, with an analysis of Wyoming bentonite.

The difference in viscosity in a water suspension of the two Tieton samples may be reflected by the chemical analysis. The marked increase in calcium in sample 2 indicates that more montmorillonite in this sample has calcium as the exchangeable cation. The higher iron content might indicate that there was more nontronite in sample 2. Also, the higher alumina and lower silica could indicate more beidellite in this sample. All these conditions tend toward lower viscosity. These contentions have been partly confirmed by differential thermal analyses.

TABLE I

CHEMICAL ANALYSES OF BENTONITE FROM TIETON DEPOS T

SAMPLE	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O
Tieton 1	68.4	0.58	12.9	1.85	2.61	0.1-1.0*	n.d.†
Tieton 2	54.5	5.15	16.5	2.95	2.32	0.1-1.0*	n.d.†
Wyoming‡	57.49	2.92	20.27	0.23	3.18	1.32	0.28

* Determined by spectrographic analysis.
† Not detected by spectrograph.
‡ Analysis from American Petroleum Research Project No. 49, "Reference Clay Minerals," American Petroleum Institute, 1951.

Measuring Sealing Properties

The bentonite was tested by two methods, one employing sealing under high pressure and the other under low pressure. In the former test an API filter press was used to contain the porous bed and the test material. In the low-pressure test a filter cell was built. The API filter is shown in Fig 3. It is an aluminum cylinder 3 in. in diameter and 4 in. high, with pressure-tight top and bottom closures. The top closure is equipped with fittings to introduce gas as a source of pressure; the bottom is fitted with a 60-mesh screen and a drain tube to allow the passage of filtrate from inside the cell. The filter paper prescribed for the wall-building test was not used. Instead, a perforated plate was placed below the screen for support when compacting the sand bed. The sand bed was composed of 20- to 35-mesh material placed in the bottom of the filter cell. After the sand was placed, 100 grams of bentonite, ground to pass 10-mesh, was distributed evenly over the sand bed and compacted in a hydraulic press. The cylinder was then filled with water and capped; after 15 minutes, 10 psi of gas pressure was introduced on top of the water. If no leakage occurred, the pressure was increased in 10-lb increments to a maximum of 100 psi and held for 15 minutes. This testing procedure was developed after about 40 trials in which the amount and particle-size distribution of the sand bed were varied. The size of the material used in the porous bed ranged from 14-in. steel balls to minus-65-mesh

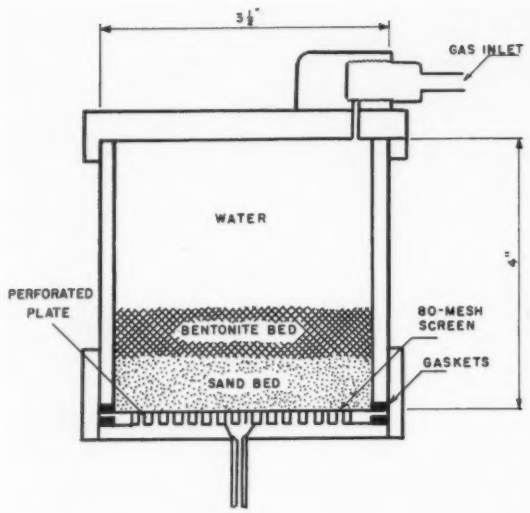

FIG. 3. SECTION THROUGH HIGH-PRESSURE FILTER TEST SHOWING BENTONITE MEMBRANE AND POROUS BED

sand. The most consistent results were obtained for the 20- to 35-mesh sand.

A low-pressure filter was constructed of a glass tube 1 $^{13}/_{16}$ in. in diameter and 14 in. long. The bottom of the tube was closed with an 80-mesh screen and a rubber stopper with a port for a drain tube open to the atmosphere. The top was also closed with a rubber stopper, and an entry was made in the stopper for introducing air pressure. A bed of either sand or gravel 4½ in. deep was placed in the bottom of the tube, and a 100-gram sample of minus-10-mesh bentonite was evenly distributed over the top of the gravel bed. Three inches of gravel or sand was used as a retaining bed over the bentonite. The equipment was sealed and 10 psi of air pressure introduced. In one test 20- to 35-mesh sand was used instead of the gravel bed; the bentonite was introduced in a slurry made by adding 5 per cent, by weight, of bentonite to water. The apparatus is shown in Fig. 4.

Wyoming bentonite, samples of the Tieton bentonite, and a commercially prepared sealing clay were used in the tests.

Other Standard Tests

During the course of the investigation the bentonites were tested by standard methods to determine possible uses in industry. Some of these tests reflect the possible quality of the bentonites for use as sealing agents. Viscosity determinations were made with a Stormer viscometer which was calibrated, using glycerol of known concentration at a controlled temperature.

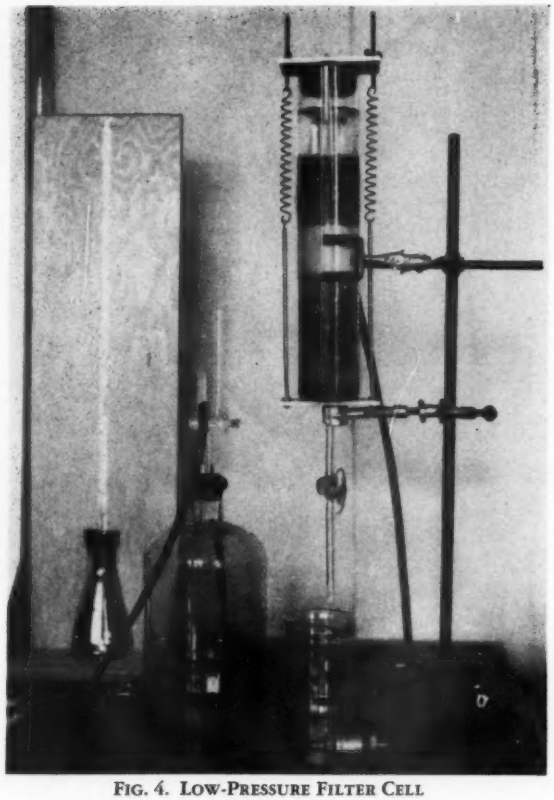

FIG. 4. LOW-PRESSURE FILTER CELL

Comparative swelling of the bentonite samples was measured as follows: 2½ grams of minus-10-mesh bentonite was placed in the bottom of a 100-ml graduate and the bentonite sample was slowly sifted into the water. After 24 hours the apparent volume of the bentonite in the bottom of the graduate was noted. The dry volume subtracted from the saturated volume and divided by the dry volume is the swelling ratio. This value is usually expressed in per cent, obtained by multiplying the ratio by 100.

The wall-building test, designed to measure the sealing effect of bentonite in a drill hole, was made in the API filter cell. A Whatman No. 50 filter paper was used over the 60-mesh screen described. A slurry of known solids content was placed in the filter cell, the cell was then capped, and a gas pressure of 100 psi was introduced. The pressure was held until no filtrate passed out through the vent in the bottom of the cell. This condition indicates that the bentonite has sealed the filter paper. The filtrate that passed through the paper before sealing was measured and used as an index of the wall-building capacity. The depth of the cake formed in sealing the filter paper was also used to indicate the sealing effect.

Bentonite as a Hydro-Seal

When a highly swelling bentonite is used as a hydro-seal, it is well mixed with water and introduced into the body of water to be contained. The bentonite is carried to the leaking areas by the water stream and is deposited. The swelling takes place there and seals the holes. This method of application depends upon the ability of the bentonite to stay in suspension long enough to be transported to the leaking area and to retain enough of its swelling capacity to close the openings through which the water is being lost. These openings must necessarily be relatively small.

A second type of sealing is to apply an impervious membrane of bentonite to the leaking area or as a preventive measure to assure retention of the water in proper channels. The bentonite is then applied as a coating to the walls of the ditches or the bottom and walls of retaining ponds. Usually a retaining bed of gravel is placed over the bentonite. The bentonite can also be applied in trenches adjacent to the walls of the channel.

Results

The capacity of a bentonite to seal has been considered a function of the swelling capacity of the particular material. Thus, the swelling capacities of the Tieton bentonite sample were compared with those of the Wyoming bentonite. Test results are given in Table II.

Table III shows the results of the sealing tests with the high-pressure filter. The first group of tests on the Tieton bentonite in Table III are shown to indicate some of the variables investigated. The second group shows test results after a standard procedure had been established. Filter cakes are shown in Fig. 5.

Low-Pressure Filter Tests

Tests also were made to determine the sealing capacity of the Tieton and Wyoming bentonite samples under pressure that might be encountered in using the bentonites to seal ditches and ponds. Instead of 100 psi, a maximum pressure of 10 psi was used. The thickness of the porous bed was increased to more closely simulate field conditions. All Tieton samples retained water for 96 hours under 10 lb of air pressure. The bentonite bed was about ¼ inch below the surface, but beneath this wetted surface the bentonite and underlying gravel bed remained dry. Under the same test conditions the Wyoming bentonite failed to retain the water. Penetration of the water through the bed started initially in isolated spots and quickly spread throughout the bed as the swelling took place. A sample of commercially prepared sealing clay also failed to hold under 10 psi of air pressure.

TABLE II

SWELLING CAPACITIES OF TIETON AND WYOMING BENTONITE

SAMPLE	DRY VOLUME (ml)	SATURATED VOLUME (ml)	VOLUME INCREASE (%)
Wyoming	2.7	27.0	900
Tieton 1	2.6	13.0	400
Tieton 2	2.6	13.0	400
Tieton 3	2.7	13.0	381
Tieton 4	2.6	22.0	746

TABLE III

RESULTS OF SEALING TESTS: HIGH-PRESSURE FILTER

SAMPLE	BENTONITE BED WEIGHT (grams)	SAND BED*		GAS PRESSURE (psi)	FILTRATE LOSS (%)
		SIZE (mesh)	WEIGHT (grams)		
Wyoming	100	20-35	100	5-7	100
Wyoming	100	20-35	100	5-7	100
Wyoming	100	20-35	100	5-7	100
Wyoming†	100	20-35	100	5-7	100
Tieton 1	140	48-65	300	100	0
Tieton 1	50	4-6	78	2-3	100
Tieton 1	50	4-6	150	20	0
Tieton 1	50	4-6	200	75	0
Tieton 1	50	4-6	200	3-5	100
Tieton 1	100	20-35	100	100	0
Tieton 2	100	20-35	100	100	0
Tieton 3	100	20-35	100	7-8	100
Tieton 3	100	20-35	100	10	100
Tieton 3	100	20-35	100	6-7	100
Tieton 4	100	20-35	100	100	0

* Porosity of 20- to 35-mesh sand bed was 38 per cent.
† Minus-200-mesh Wyoming bentonite was used in this test.

When the Wyoming bentonite was applied to a 20- to 35-mesh sand bed, as a 5 per cent suspension in water, the Wyoming bentonite held. The porous bed was successfully sealed, and after a week without pressure there was no leakage. None of the Tieton samples sealed the sand bed when applied as a slurry, except sample 4. The swelling characteristics of this sample approached those of the Wyoming bentonite. When the gravel bed was used and the bentonite applied as a slurry, none of the samples tested sealed the bed.

Viscosity and Wall-Bearing Tests

Viscosity was measured, and the wall-building capacities of all local bentonite samples investigated were tested to evaluate their use as drilling-fluid additives. None appeared to hold much promise for this use, principally because of the low viscosity of the water suspensions. The Tieton samples, however, were better than most in sealing the filter cells with comparatively small loss of filtrate and by the

FIG. 5. CAKES REMOVED FROM HIGH-PRESSURE FILTER CELL

Left: Wyoming bentonite. *Right:* Tieton bentonite. Note that the Tieton sample is wet only on the surface.

thin membrane necessary to seal the filter. Results in the viscosity measurements are shown graphically in Fig. 6, and the wall-building test results are tabulated in Table IV. The suspensions tested were those used in preparing viscosity curves.

Discussion of Results

Laboratory tests indicate that when applied as a membrane the Tieton bentonite has excellent ability to seal porous beds against water loss. The material is inferior to the Wyoming bentonite when it is applied as a slurry. As a membrane lining, however, the Tieton bentonite can seal beds that have larger pores than by applying a swelling bentonite as a slurry. The swelling capacity of the Tieton bentonite samples varies because of changes in the sodium bentonite. This variation in swelling is also a result of the presence of unaltered material, residual non-plastic minerals, and the degree of alteration of the volcanic parent rock to bentonite.

Failure of the high-swelling Wyoming bentonite to seal porous beds when applied as a membrane is a direct result of its high swelling property. In the tests with the high-pressure filter, swelling started immediately on introduction of water. Where some water penetrated the bentonite bed, these areas were rapidly enlarged by the swelling action. As a result, the effective membrane became increasingly thinner as the swelling permitted further penetration of the water and progressive wetting of the bed to greater and greater depths. Filter cakes removed showed almost complete wetting of the bentonite bed. When the Tieton bentonite was used, only a thin layer on top of the bed was wetted, and the bentonite and sand bed below were completely dry. Little difference was observed in the depth of wetting of the bentonite when 10 or 100 psi pressure was applied.

These differences between the two types of bentonite prevailed when the material was applied as a membrane. Application of the bentonite in slurry form, however, proved the Wyoming bentonite to be much more effective.

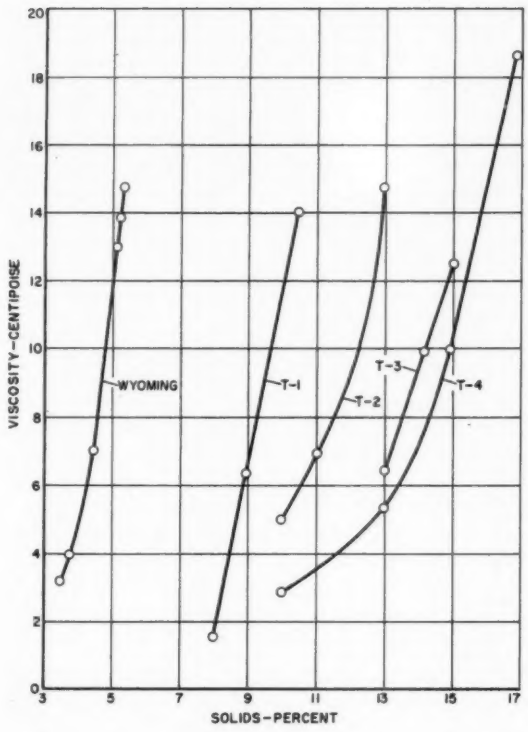

TABLE IV
VISCOSITY TEST RESULTS

SAMPLE	SOLIDS IN SLURRY (%)	FILTRATE LOSS (ml)	CAKE THICKNESS (1/32 in.)
Tieton 1	8.0	20.3	3
Tieton 1	9.0	16.4	3
Tieton 1	10.5	12.8	3
Tieton 1	12.0	11.5	3
Tieton 2	10.0	16.4	4
Tieton 2	11.0	13.6	3
Tieton 2	12.0	12.6	3
Tieton 2	13.0	11.7	3
Tieton 3	13.0	12.1	3
Tieton 3	14.0	11.4	3
Tieton 3	15.0	9.2	3
Tieton 4	10.0	17.2	3
Tieton 4	13.0	13.6	3
Tieton 4	15.0	11.8	3
Tieton 4	16.8	10.0	4
Wyoming	5.2	10.1	3

FIG. 6. VISCOSITY OF TIETON AND WYOMING BENTONITES

Commercial Significance

The advantageous location of the Tieton deposit for Statewide use plus the extensive development of irrigation canals, reservoirs, and other water-containing structures in the State should stimulate use of the material. Application of the bentonite as a membrane lining in these ditches, canals, and water-storage reservoirs will materially reduce the loss of water by seepage. This result has the dual advantage of allowing maximum use of the water where it is desired and of minimizing the occurrence of the water where it is not wanted. Very limited use of the bentonite by the Bureau of Reclamation in the Grand Coulee Project has borne out the laboratory testing. Rather general use of the material by individual farmers in the Yakima area has also indicated its utility as a sealing agent.

Application of the bentonite as a membrane is in many instances somewhat more expensive than application as a slurry, but the transportation advantage of the Tieton bentonite over the nearest source of high-swelling bentonite should help to equalize the additional cost of application.

These test data indicate that, in many intances at least, local use could be made of many of the nonswelling bentonites as a hydro-sealing agent. The swelling bentonites have long been used for this purpose, but the rather restricted occurrence of this type of bentonite often results in high transportation costs. Bentonites of the nonswelling type are rather widely distributed, and most localities have access to some such material.

ACKNOWLEDGMENTS

This report is the result of an investigation made under a cooperative agreement between the Bureau of Mines, United States Department of the Interior, and the School of Mineral Engineering of the University of Washington. Chemical analyses and the electron micrographs were made by the Bureau of Mines Electro-development Laboratory, Albany, Oregon.

REFERENCES

Recommended Practice for Standard Field Procedure for Testing Drilling Fluids, R. P. 29, American Petroleum Institute, New York, 1950.

Grim, Ralph E., *Clay Mineralogy*, McGraw-Hill Book Company, Inc., New York, 1953.

"Reference Clay Minerals," A. P. I. Research Project 49, American Petroleum Institute, New York, 1951.

The Northwest Experiment Station

THE NORTHWEST EXPERIMENT STATION of the Bureau of Mines was established on the University of Washington campus in December, 1916, following spirited competition with various other localities in the Pacific Northwest. Originally the Bureau of Mines and the State of Washington each provided $20,000 annually for its maintenance.

For many years the principal problems of the Station were concerned with the needs of the mineral industry in the Pacific Northwest and Alaska. The chief problems were electrometallurgy, coal mining and preparation, and ceramics. From the beginning, the University of Washington has provided from four to six graduate research fellows who devote about one-half of their time to projects directed by the staff of the Station.

The work on coal now deals with preparation, carbonization, gasification, combustion, and other utilization problems. Similar work done on the nonmetallic minerals usually involves phases of beneficiation, utilization, and some resources studies.

In the nonmetallics field, an investigation of the clays and shales of Washington and Oregon for use in making expanded aggregates, refractories, and whiteware has been carried on. Felspar deposits of the Northwest are being examined as a phase of an electrical-porcelain study. The study and evaluation of the clay samples from Washington and Oregon is a continuing project.

The equipment and facilities are for the most part provided by the University. These include a four-story reinforced concrete and brick building housing the laboratory and office quarters for both the Bureau of Mines and the School of Mineral Engineering of the University, an additional kiln building, and the coal-preparation laboratory, which has facilities and equipment that are considered superior to those of any other such laboratory in the United States.

For the nonmetallic and ceramic investigations, in addition to the usual items, there are a special kiln with sillimanite lining for firing 3000° F, thermal analysis and Phillips X-ray diffraction apparatus for identifying clay and other nonmetallic minerals at high temperatures, and a 225-ton double acting, hydraulic press for forming brick.

Since its establishment, the Northwest Experiment Station has been the source of some 200 publications, appearing either in Engineering Experiment Station bulletins, technological journals, or as Bureau of Mines reports.

Dr. H. F. Yancey, Superintendent of the Northwest Station since 1928, has a present staff of ten engineers and chemists, three of whom have been appointed lecturers in the University and who supervise graduate students. Cooperative graduate fellowships have also contributed materially to the research work and development of the School of Mineral Engineering.

A ROTATION INDICATOR FOR PLASTIC BENDING TESTS

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H. Erlijman

Introduction

The rotation indicator is a gage or a set of gages indicating the angle change between two cross sections of a flexural member under the process of bending. The construction of such a gage is relatively simple. Two dial gages, mounted at the extremities of two bars rigidly connected with the two cross sections of the member, will suffice.[1] The readings of the dials and the length of the rigid arms being known, the change of the angle is easily computed.

The information furnished by the rotation indicator usually is utilized in establishing moment-rotation (M-ϕ) relationship of a given structural member, especially in connection with the study of formation of plastic hinges. In such a case, the instrument should follow the deformation up to several degrees, and the importance of the small angle changes in the elastic range is relatively minor.

In order to investigate the flexural behavior of structural steel beams in the plastic range at low temperatures, a special type of gage had to be provided. The first requirement the gage had to fulfill was to provide for remote readings, outside of the cooling box enclosing the beam specimen. For practical reasons, the device had to be designed, if possible, so as to serve its purpose in several successive tests.

The choice fell upon the so-called clip-gages, elastic straps, with SR-4 gages being the sensing element, as described hereafter.

Principle of Operation

If the end points of a thin metal strap are displaced toward each other and if some initial eccentricity is provided, the strap will buckle and take a curved shape and all strains within will still remain elastic. If the dimensions are properly chosen, a very nearly linear relation will exist between the curvature (and thus the strain measured on the strap) and the displacement of the end points.

[1] See "Progress Report No. 7: Welded Continuous Frames and Their Collapse," *Weld. Jour. Res. Supp.*, Sept., 1954.

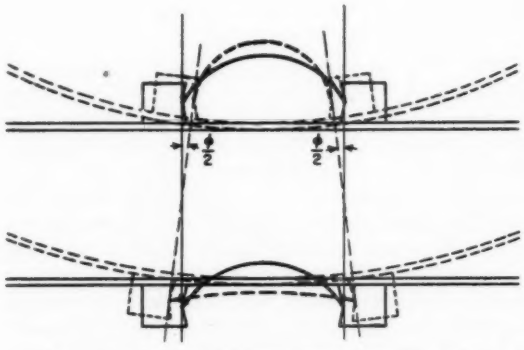
D. D. Vasarhelyi

This principle can be utilized as follows in a rotation indicator (Fig. 1).

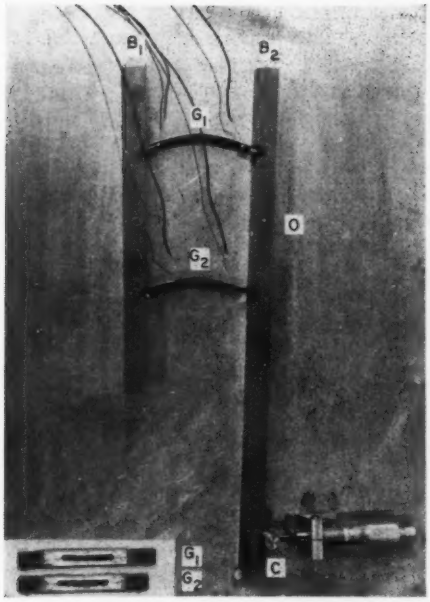
Four supporting points are provided, two on the tension and two on the compression side of the short beam section over which the angle change of the cross section has to be measured. To follow the bending process, slightly compressed straps are placed between the supports on both the compression and the tension side of the beam. When the load is applied, one will increase its curvature and the other will tend to flatten. SR-4 gages attached to the convex side of both straps will indicate a decrease of the original strain on one, an increase on the other. The SR-4 gages being attached to the indicator in the same manner as in the case of a simple bending test, the sum of the changes will be measured, and at the same time, the setup will be self-compensating for temperature changes, provided the two straps have the same temperature, a requisite easy to maintain. The strain readings from the pair of straps in the rotation indicator can consequently be calibrated to supply directly the change in angle, ϕ.

Calibration of the Rotation Indicator

In order to obtain the values of ϕ from the SR-4 readings during tests, a special calibration device



F.G. 1. DIAGRAM SHOWING THE PRINCIPLE OF A ROTATION INDICATOR ON A BEAM



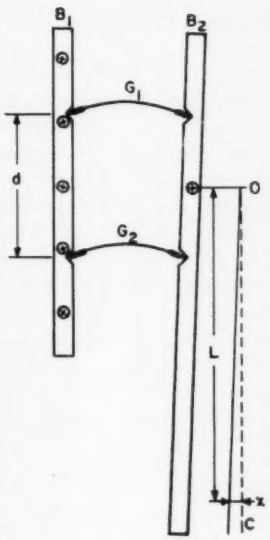


FIG. 2. CALIBRATION RIG FOR ROTATION INDICATOR

was manufactured (Fig. 2). Two metal bars, B1 and B2, with V notches were mounted on a board. One of the bars (B2) can rotate around a point, O, the rotation being caused and controlled by means of a micrometer which acts against the rotating bar at C. Two strap gages, G1 and G2, were mounted between the V notches of the bars which were separated the same distance, d, as the actual supporting frames would be on the beam. Note that by placing the gages with initial curvature in the same direction, as shown in Fig. 2, the effects are added in the indicator circuit, and the dual system is self-compensating. Suppose now a displacement, x, of the movable bar at the point, C, which will be accurately measured by the micrometer. The angle of rotation, ϕ, symbolizing the rotation of the loaded section on the beam, will be arc tan x/l, or, for angles less than 4°, about equal to x/l. For different values of x, then, a set of values of ϕ can be obtained and correlated with the corresponding readings in the SR-4 indicator. Thus a ϕ-SR-4-readings curve is drawn, which is the calibration curve of the gages used as a rotation indicator.

The calibration board can, of course, be improved by some minor details. For instance, a scale with angle units and fractions can be used on the board; thus angle ϕ would be read directly.

Every set of gages intended to be used on the beam test was tested and calibrated, and the results gave a highly satisfactory linear calibration. (See Fig. 3.)

This basic calibration was carried out at room temperature. The calibration for several units was repeated at -45° F, by enclosing the whole calibration board in dry ice and measuring its temperature by thermocouples. The readings gave the same linear relationship as the ones obtained at room temperature, thus proving that the setup is truly temperature-compensated and that the same gage factor can be used in both room and low-temperature tests.

As a fast check of the proper working of the setup, the straps can be arranged in such a way that one SR-4 gage is on the concave side while the other is on the convex side; thus the SR-4 strain readings will cancel.

The straps, after exploration with several materials, were made from 0.005-in. (thick) phosphor bronze sheet stock, $\frac{7}{16}$ in. wide. The ends of the straps were soldered to steel knife-edged blocks (Figs. 2 and 4), which provided the setup with initial eccentricity and with the least resistance in rotation in the V-slots of the gage holders. The strap units can be seen on the lower left corner of Fig. 2. They were made in two lengths, 4.00 in. and 4.20 in., between the knife-edges. The longer one was used on the tension side of the beam and the extra length was provided for supplying enough arching which was gradually released during the test. The short one was just slightly arched in the initial position, but its curvature gradually increased as the bending proceeded.

One A-12 type of SR-4 gage was mounted on each strap, using SR-4 cement, and the usual precautions were taken in the gage application.

Since the brass straps are very light and flexible, the motion of the wires connecting the gages to the indicator might produce uncontrollable interferences. This danger was eliminated in part by the weight of the steel knife-edges, and by the use of especially flexible lead wires.

In order to follow exactly the deformation of the specimen, the rotation indicators were mounted between pairs of rectangular frames rigidly attached to the beam as shown clearly in Fig. 4.

Each of these frames consists of a yoke, Y, made of two relatively rigid bars, touching the flange of the beam at two sockets machined out of the bars and pulled together and held tightly against the

beam flanges by two long screws with winged nuts at one end. This arrangement assures that the yokes stay at the section during the bending of the beam. Welding the fixtures to the specimen had to be avoided since additional stress raisers may interfere with the behavior of the beam at low temperature.

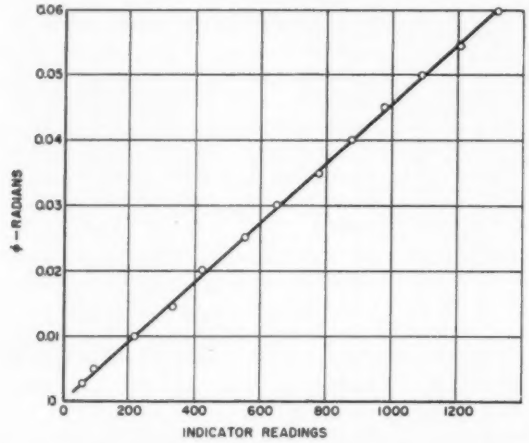


FIG. 3. CALIBRATION CURVE OF A STRAP-GAGE ROTATION INDICATOR

The bars, V, with V notches holding the gage straps, are independent from the yoke bars, but in close contact with them and pivoting around a longitudinal horizontal pin, P. Two set screws in the notched bars permit them to be exactly positioned relative to the flanges. Thus, while the yokes may not be parallel because of possible imperfections of the flanges or unequal pull of the holding screws, the bars can always be set in a satisfactory position.

At every cross section where rotation measurements are desired, two sets of gages are provided, one on each side.

Conclusion

The rotation indicator, as described, provides a simple and satisfactory means to obtain M-ϕ relations during the formation of plastic hinges in beams. It is a self-compensating unit which supplies readings through a remote indicator, and thus is suitable for controlled temperature tests. The same instrumentation could easily be adopted for continuous recording of the flexural procedure.

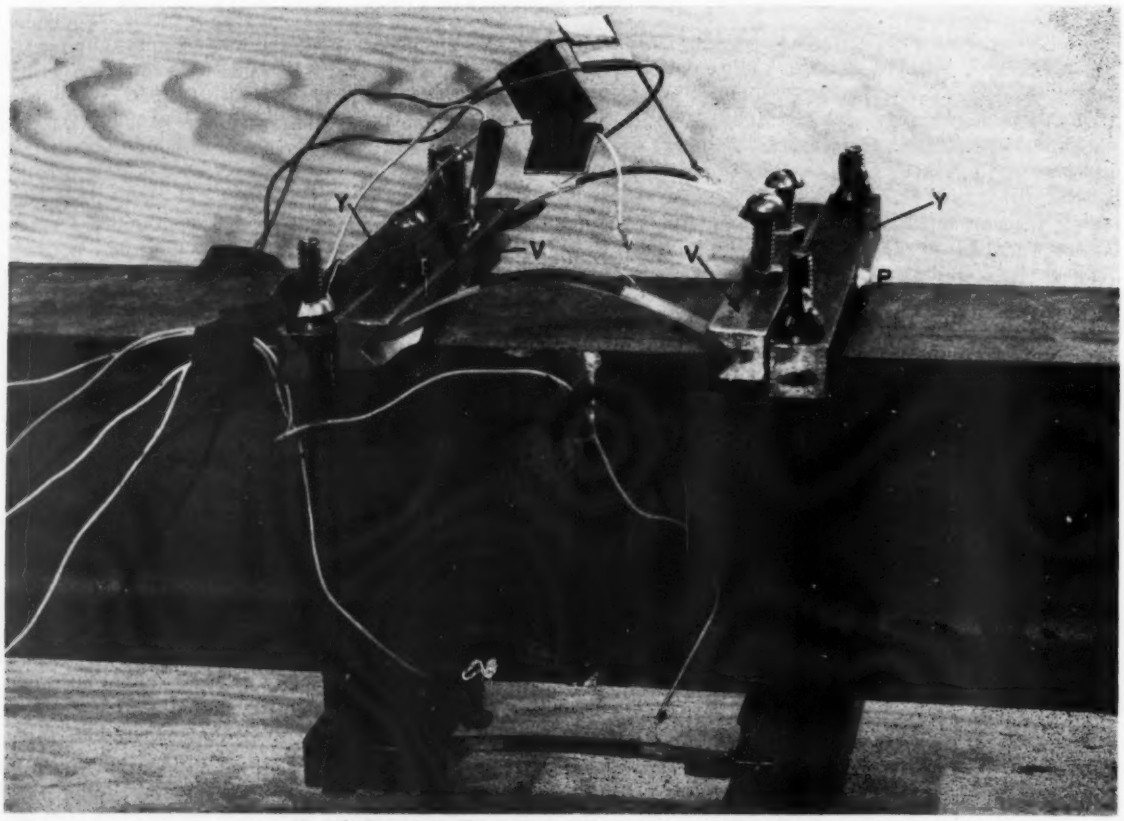


FIG. 4. ROTATION INDICATOR MOUNTED ON A TEST BEAM

VACUUM METALLURGY

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E. C. Roberts

High vacuum as a metallurgical processing tool has proved one of the most important laboratory-to-industry transitions of the past decade. While vacuum techniques in the fields of analysis and highly specialized metal reaction studies have proved their usefulness on a small scale for a considerable period in the era of metallurgical scientific investigation, only recently have the complications they introduce in metal production shown themselves to be worth the trouble. Three major activities of our times have contributed largely to the rapid acceptance and application of vacuum techniques in metal production. First, the aircraft industry, with its continuing demands for stronger, lighter, more consistently dependable materials for both piloted and pilotless machines, has doubled its demands on the metallurgist for each ten per cent increase in speed. Second, the nuclear energy field with its imposing list of requirements for both fissile and structural materials for nuclear reactors represents an entirely new realm of metallurgical problems. In the third place, the rapidly growing electronics industry is finding accentuated needs for purer and purer metallic components. In this latter field alone, the highly important transistor developments could not have even begun were it not for the expansion of laboratory methods for single crystal growth into production techniques. In each of these immense industrial fields, vacuum processing has made, and will continue to make, its contributions.

Primarily, the applications of vacuum techniques have stemmed from our increasing awareness of the presence and the effects of gaseous (dissolved) and solid (undissolved) impurities in metals. Two separate and distinct undesirable categories are not represented by these two terms, since the impurities are quite frequently gaseous compound inclusions. Nor are they undesirable in all instances. A certain controlled amount of gas evolution during the liquid-to-solid transition has proved very useful in a number of circumstances, e.g., the manufacture of rimming steel ingots and the casting of copper wire bar. In the high-temperature metals field metallurgists are concentrating considerable study on the deliberate, if minor, addition of nonmetallic powder to metals to assist in grain boundary strengthening. On the other hand, the embrittlement of certain metals, unsoundness of castings, the deleterious effects on magnetic and other physical properties, and the many difficulties arising in fabrication as a result of the gases or their aforementioned solid compounds have focused the attention of many modern metallurgists on the advantages of metals with low gas content.

One of the specific major reasons for the recent interest in vacuum treatments has been the greatly increased importance of a series of elements that are rather broadly included under the classification, "reactive metals." The prototype of these commercially new metals is, of course, titanium, and the development and industrial expansion of vacuum processing has virtually paralleled the production growth of this metal and its alloys.*

While the greatest expansion in vacuum metallurgy has taken place in the titanium industry, its usefulness in the extraction and processing of other metals by methods not applicable to titanium has been demonstrated. Less publicized but highly important applications are being made in the tonnage production of high-strength steels. In these latter, the obtaining of useful transverse ductilities (of the order of 6 to 10 per cent), at ultimate tensile strengths of 250,000 to 300,000 psi, has been effected through proper alloying and vacuum processing. In each of these cases gaseous contamination is being limited to fixed maximums measured in parts per million. Other alloys, particularly those of the high-melting reactive metals (such as zirconium, molybdenum, tungsten, tantalum, columbium, and chromium) cannot be made in sufficient purity by conventional methods. These applications alone would have been sufficient to demonstrate that vacuum metal treatment is not only technically desirable but commercially feasible. Other processes have served to emphasize this conclusion.

Thermal Reduction

The Pidgeon Process for the production of magnesium through the reduction of dolomite by ferrosilicon is an excellent example of the type of process

* Seventy million pounds of titanium and titanium alloys is the U. S. production objective for 1957.

in which low pressure favors a reaction by which a metal is extracted from a concentrate. In this process a highly reactive metal is produced in its most reactive state, metal vapor. While the reaction by which the vapor is produced could proceed at considerably higher pressures, the low pressure used (100 microns or less) assures that residual atmospheric gases are reduced to percentages at which the amount of contamination is negligible.

Analogous processes have been used for some time in the production of zinc. While the actual details of operation vary considerably among the different producers, the prevention of the formation of "blue powder," or zinc oxide, has been a major factor influencing the development of vacuum techniques.

Processes of a similar nature have also been developed for the production of calcium and lithium which are usually produced by the electrolysis of molten salts. Calcium vacuum-extracted on a production basis has been shown to be not only of equivalent purity to distilled electrolytic metal but to cost only a fraction as much. Barium and cesium can likewise be obtained on a production scale.

High thermal decomposition pressures have allowed the preparation of limited amounts of titanium and zirconium through the decomposition of the tetraiodides of these metals. The metal so produced is of extremely high purity and has been invaluable for research purposes.

Distillation

Distillation processes for purification are applicable to metals having sufficiently high vapor pressures within the temperature range of operation of evacuable containers. Among the metals which are included in this category are lithium, sodium, potassium, magnesium, calcium, cadmium, zinc, arsenic, antimony, bismuth, tellurium, lead, and even chromium and manganese. A sufficient vapor pressure is not the only prerequisite for profitable application of the vapor purification technique. The feasibility of purification of a metal by distillation depends principally on three factors: (1) the relative volatility of the impurities, or their likelihood of being distilled along with the metal, (2) the tendency for the vapor pressure and rate of vaporization of the metal to be decreased by the formation of compounds with impurities, and (3) the possibility of the metal and impurities forming volatile compounds which may be vaporized simultaneously.

In spite of these problems, distillation has provided a means of obtaining substantial purification of several metals. As in the thermal reductions, many distillation processes can be conducted at atmospheric pressures. However, the use of evacuated systems has quite frequently provided a lower reaction temperature and a decreased reaction with atmospheric contaminants.

Distillation of the major metal constituent ideally results in retaining the undesirable substances in the reaction chamber. Vacuum distillation has also been utilized for the removal of volatile impurities from a metal whose vapor pressure is considerably higher than that of its contaminants. An example of this latter type of process is the removal of zinc by distillation in the final refining process for lead at the St. Joseph Lead Co. The zinc present is part of the zinc powder addition during the desilverizing process. The silver-rich crusts which form are themselves later subjected to a high-temperature vacuum treatment for the removal of both the zinc and lead impurities in the silver. Vacuum processing in the lead industry has resulted in much better working conditions, lower operating cost, and the separation of valuable and useful by-products. Something of an extension of this idea has been applied in scrap reclamation and in the separation of one metal from a metallic solvent after a solvent-extraction operation. An example of the former is the separation of zinc and lead from scrap brass, leaving residual copper. The separation of aluminum and zinc after preliminary extraction of the aluminum from crude aluminum-silicon alloy by solution in zinc is an example of the latter.

In the purification of sponge titanium and sponge zirconium, originally prepared by the Kroll Process, a distillation treatment is used for the removal of both magnesium and magnesium chloride. These distillates are recondensed and re-used.

Most distillation processes are not without certain drawbacks: (1) they are batch-type operations, (2) heat transfer is difficult in vacuum systems, (3) construction materials are limited in number. However, these problems are being or will be solved as the demand for purity in certain metals increases.

Melting and Casting

Gases in metals vary in the nature of their occurrence and in their distribution in the metal structure. The most obvious effect of gases on metals is the formation of blowholes during the solidification of a casting. As the quantity of gas per unit volume of metal decreases and its distribution is extended, the cavities between the particles decrease in size, first to "pinhole" porosity and finally to microporosity visible only at high magnification. The gas evolved in a particular casting operation may be due to a change of solubility in the transition from the liquid to solid state. A second general source of gases during solidification is as a product of a chemical reaction such as that of hydrogen and oxygen to give water vapor, or between carbon and oxygen forming carbon monoxide. Reactions between the reducing

agents and metal oxides give identical reaction products in certain metals. Any instance of gas evolution during phase transition obviously can be completely prevented by the removal of one or more of the gaseous components from the liquid metal. For many years this has been accomplished by the addition of another element which ties up one of the gases as a refractory compound. This is what occurs in the killing of steel with aluminum, resulting in the removal of oxygen from solution and the formation of aluminum oxide. It also is the objective in the phosphorous deoxidation of copper. In each instance oxygen is removed but oxide inclusions and residual deoxidant in solution remain to exert their possibly undesirable effects on properties for particular applications. Examples are numerous. The required conductivities of certain high-purity copper castings for the electrical and electronics industries are such that the use of solid deoxidants, with their consequent increase in resistance, can no longer be tolerated. Aluminum-killed steel has long been marked by the poor surface characteristics of the sheet rolled therefrom.

The vacuum process also offers a method for the reduction of impurities which are volatile at the operating conditions, a more efficient utilization of highly reactive metal additions as true alloying elements, and the elimination of expensive melt losses. These latter two go hand in hand. In addition, vacuum melting and casting has provided metal products which might otherwise never have become available. It has provided, on a commercial scale, molybdenum alloys of superior strength and stiffness at elevated temperatures, and has established itself as a vital part of the process by means of which thousands of tons of uranium of extraordinary purity have been produced. It has proved indispensable in the production of titanium and zirconium and their alloys and has considerably increased the safety of large pieces of steel used in such critical services as steam and gas turbine shafts and rotors for electrical machinery. Practically, the problems have been many but, as in vacuum distillation, the difficulties are progressively being surmounted.

Since the melting and casting operation is so important in the stages of processing a metal, it is not surprising that a diversity of vacuum techniques have been studied. These are arranged in order of increasing purity of product.

1) *Induction Vacuum Melting.* Impurity contents of the order of 0.01 per cent can be achieved. Most of the impurity is from the crucible.

2) *Arc Vacuum Melting.* Impurities are about 0.001 per cent. The cold crucible process is used for high-melting, highly reactive metal production and makes possible ductile titanium, zirconium, and molybdenum.

3) *Levitation Melting.* Impurities are in the range of 0.0001 per cent. Melting and refining are done by suspending the metal in a magnetic field and providing gaseous reagents. It has not been adapted to commercial production because of numerous practical problems.

4) *Zone Melting.* Impurities are 0.00001 per cent or less. This technique is important where purity is greater than normal analytical limits, i.e., in producing germanium and silicon single crystals for transistor applications. Purities are achieved by taking advantage of the greater solubilities of impurities in the liquid over the solid phase. By a series of melting and solidification operations, the impurities are accumulated at one end of the ingot and those remaining in solution are reduced to a few parts per million. Zone melting is of great commercial importance to semiconductor-materials production.

Vacuum melting and casting has assumed such importance in the manufacture of many specialty alloys that it is becoming rather commonplace in many metal-producing facilities. Adaptations have also been made for welding and soldering in vacuum, both simply being specialized melting and casting operations.

Heat Treatment

Probably the newest and least exploited of the vacuum techniques is the vacuum heat treatment of metals. Consequently, and because of the many different reasons for heat treating, commercial possibilities for such operations seem very great. Protection from exposure to ordinary atmospheres during heat treatment has been especially critical in the tool steel industry. Prepared atmospheres of known "carbon potential" have proved indispensable in preventing oxidation and decarburization of these expensive alloys. However, none of the usual prepared atmospheres is inert to the metal being treated since all are mixtures of chemically active gases. In the heat treatment of the "reactive metals" they are not useful at all. Titanium, zirconium, vanadium, tantalum, columbium, and most of the radioactive elements require either truly inert atmospheres or vacuum for proper heat treatment. These elements have such a high free energy of compound formation with common atmospheric components such as nitrogen, oxygen and hydrogen (and with carbon from a number of possible sources), that they must be heat-treated only under the proper conditions. Prepared atmospheres, salt baths, or even inert atmospheres, are likely to introduce a gas into a metal being

treated, while the same metal treated by vacuum techniques will probably have the same contaminants extracted. This is true whether the gases are simply in solution in the metal, and thus can diffuse out through the metal lattice at a fairly rapid rate at high temperatures, or whether they have formed easily decomposed gas-metal compounds. Fortunately, the nitrides and hydrides of most common metals have high dissociation pressures and therefore are not stable in vacuum. (Only a limited amount of information is available on the dissociation pressures of metal oxides.) Thus vacuum heat treatment can be used to prevent the formation of unwanted compounds, to remove gases from solution, to decompose at least some gas-metal compounds, and to carry away any gases evolved. Vacuum processing is also generally cheaper than prepared atmosphere treatment and, in some instances, has even been used to remove the rolling oils from coiled sheet.

Heat treating in vacuum has been shown to have several important advantages from the standpoint of mechanical properties and surface condition. Fatigue strength, which is highly dependent on surface condition, may be bettered by elimination of gas-metal reactions which weaken the surface or create stress-raising surface cavities. This has been found particularly true in the extension of the fatigue life of beryllium copper springs and other fine spring material. Impact energy levels in some iron-chromium alloys have been substantially increased by decreasing the amount of oxygen present. The oxygen apparently is in the form of undissolved oxides which, at times, markedly lower the impact resistance.

The disadvantages of vacuum heat treating are fairly obvious. Again, we have the problem of batch-type operations; likewise, that of heat transfer again arises, especially below radiant temperatures (approximately 1100° F). Rapid transfer of hot metal to a quenching bath is difficult. There are also the problems of measuring the degree of vacuum obtained and determining just what degree is required.

However, annealing, aging, tempering, and many other solid-state changes have been done via vacuum heat treatments. In this day of highly specialized materials in which a maximum amount of service and dependability is demanded, the slightly added cost of vacuum processing of metals is a small factor in terms of the advantages gained.

Notes and Comments

STATE SURVIVAL PLAN

The State of Washington, which has a contract with the Federal Civil Defense Administration to conduct a Civil Defense Survival Plan Study, has made a subcontract with the University to conduct Phase I of this study. Professor R. G. Hennes of the Department of Civil Engineering is in charge of the project.

The nineteen areas of study include:

1) Location of population; 2) Analysis of population; 3) Transportation availability; 4) Movement capabilities; 5) Traffic control; 6) Communcations requirements; 7) Service coordination; 8) Political jurisdiction coordination; 9) Reception area analysis; 10) Shelter availability; 11) Internal alerting capabilities; 12) Special assistance groups; 13) Institutional requirements; 14) Utilization of government resources; 15) Logistical support; 16) Promotional analysis; 17) Industrial population reception; 18) Return and resettlement analysis; 19) Continuity of government.

The staff, which includes 21 graduate students, has been divided into seven sections. These, with their directors, are: *Population:* H. J. Graalfs, Instructor in Sociology; *Command and Control:* W. J. Gore, Instructor in Political Science; *Movement:* M. I. Ekse, Associate Professor of Civil Engineering; *Shelter:* J. R. Clanton, Associate Professor of Civil Engineering; *Reception and Care:* R. G. Tyler, Professor Emeritus of Sanitary Engineering; and W. L. Garrison, Assistant Professor of Geography; *Resources:* M. E. Marts, Associate Professor of Geography; *Public Information and Training:* H. M. Brier, Associate Professor of Journalism.

Phase I, which is concerned with the assembly and study of the nineteen areas listed above, will be completed by October 15, 1956. Phase II will cover analysis and coordination of the data gathered; Phase III will deal with the preparation of operational plans for target and support areas, and Phase IV with the testing of the various plans.

ENGINEERS IN THE NEWS

Harold E. Wessman, Dean of the College of Engineering, presided over a conference of 150 engineering deans and college presidents during the program sponsored by the Atomic Energy Commission at Oak Ridge, September 5-8.

Three engineering faculty members were engaged on the General Electric atomic project at Hanford during the summer. **R. W. Moulton,** Professor of Chemical Engineering and Executive Officer of the Department, was assigned to pile operations; **R. H. Bogan,** Assistant Professor of Civil Engineering, investigated sanitation and radioactive waste problems; **J. E. Firey,** Assistant Professor of Mechanical Engineering, dealt with mechanical processes.

A. L. Babb, Assistant Professor of Chemical Engineering, and **P. J. Waibler,** Assistant Professor of Mechanical Engineering, studied in the Nuclear Engineering Institute at the Argonne National Laboratory during July and August. Purpose of the Institute is to provide engineering college faculty members with advanced information on nuclear energy, in order that they may incorporate it into their courses of instruction.

H. C. Martin, Professor of Aeronautical Engineering, is on leave for the school year, 1956-57, to teach at the University of Hawaii.

Microwave-Tube Research Sponsored By National Science Foundation

A. E. Harrison

A contract recently signed by the National Science Foundation provides a grant totaling $22,100.00 over a period of two years to support a study of "Modulation Characteristics of Microwave Tubes" by Dr. A. E. Harrison, Professor of Electrical Engineering.

The project can be described briefly as an investigation of the intermodulation properties of traveling-wave tube amplifiers in the frequency region between 2000 and 4000 megacycles per second. The effect of an undesired signal on the magnitude and phase of the desired signal in a microwave system will be measured. It is the cross modulation, not the direct interference, which is of interest. The project will ultimately require three years for completion.

Dr. Harrison's interest in microwave tubes started before he came to the University, during his association with the Sperry Gyroscope Company, when he was engaged in klystron research and development.

In 1949, under Dr. Harrison's supervision, research on the modulation properties of microwave tubes was initiated at the University of Washington, sponsored by the Engineering Experiment Station. The work was expanded in 1951 under the Office of Naval Research Contract No. N8-onr-52012 on "Modulation Characteristics of Microwave Tubes." Since April 1, 1953, the work has been continued with the support of the Engineering Experiment Station.

Results of the work under the ONR contract were reported in University of Washington E.E. report No. 15, "Cross Modulation in Traveling-Wave Tube Amplifiers," by Arthur W. C. Nation and A. E. Harrison. Other technical reports in this field which have been issued are E.E. Report No. 13, "A Method of Forming a Broad-Band Microwave Frequency Spectrum," by R. E. Wall; an M.S. thesis by Joseph W. Christie entitled "An Investigation of Traveling-Wave Tube Phase-Shift Phenomena due to Nonlinearity and Cross Modulation"; and E.E. Report No. 20, "Notes on Modulation and Noise on the Basis of Liouville's Equation," by G. Held.

Work up to the present time has emphasized techniques of measurements rather than data on tube characteristics. Cross modulation in an amplifier when a c.w. interfering signal is present was measured by separating the signals in the output with a cavity-resonator type filter and displaying the amplitude of the desired signal on a cathode-ray oscilloscope. Provision for amplifying small changes in the intensity of the desired signal when interference is present, without sacrificing information on the amplitude of the desired signal, permits the determination of small values of cross modulation with considerable accuracy. Equipment for making the measurements was built and tested.

The original tests were made on a traveling-wave tube which did not have sufficient gain for practical applications, and the tests will be repeated with a tube with normal operating characteristics, preferably a commercially available traveling-wave tube amplifier. These results would then be of general interest.

Extension of the project to the measurement of cross modulation between frequency-modulated signals in a traveling-wave tube amplifier is also contemplated. The importance of this factor in the design of receiving systems is rather obvious. A microwave spectrum analyzer will be used to determine the intermodulation products when frequency modulation of the interfering signal is present. The equipment will replace the high-Q cavity resonator used as a filter to separate the intermodulation components when a c.w. interfering signal is used. The problem will also be analyzed from a theoretical standpoint.

The project will not be limited to the narrow field of investigating interference between frequency modulated signals outlined above, but this phase of the problem is proposed as the next step in a broad program to investigate the modulation properties of various types of microwave amplifiers.

Dr. Harrison will be assisted by two students working towards Master's or Doctor's degrees.

GERMAN ENGINEER LECTURES ON GLACIERS

Dr. Ing. Walther Hofmann, Konservator of the Photogrammetric Institute of the Technische Hochschule, Munich, Germany, lectured at the University September 25 and 27 on "Glaciers of the Alps and Andes" and "Measurement of Glaciers."

Earthquake Investigation at the University of Washington

Seismologist, Department of Geology

FRANK NEUMANN

F. Neumann

The first Puget Sound earthquake appearing in a historical record occurred in 1833. In 1906, following fast on the disastrous earthquake that wiped out San Francisco, a Bosch-Omori seismograph was installed on the campus of the University of Washington. Although this instrument magnified ground vibrations only 35 times, registered on smoked paper, and had an inadequate time-control system, it was considered a standard piece of equipment in its day and up through the Twenties. It contributed materially toward the improvement of international travel-time tables that were used in locating earthquakes and were ultimately used in establishing the fact that, contrary to prevailing opinion, earthquakes could originate at depths as great as 450 miles. With such equipment, however, regional earthquakes were never located with sufficient accuracy to associate them with local faults, to ascertain their depths, nor to help appreciably in delineating local crustal structure. The development of more accurate time controls and the introduction of shorter period seismometer pendulums with high magnification subsequently relegated the Bosch-Omori to obsolescence. Only in the case of local shocks of destructive intensity does this type of instrument now contribute anything at all toward a better understanding of earthquake phenomena.

A series of damaging shocks in 1946 and the destructive shock of April 13, 1949, revived general concern over earthquakes in the Puget Sound area and it was at that time that Professor G. E. Goodspeed, then Executive Officer of the Geology Department, obtained a grant that enabled him to establish a first-class station on the campus and purchase equipment for a small number of auxiliary stations. It had then become clearly evident that if any return was to be realized from local earthquake investigations a prerequisite was the establishment of a network of first-class stations in the area under study. At this writing, for example, there are ten stations operating in the northern California area under the sponsorship of the University of California with a central station at Berkeley, while a comparable number are operating in southern California under the California Institute of Technology. Professor Goodspeed installed five seismograph units in a new seismograph room in the basement of Johnson Hall in 1949, but various difficulties prevented the immediate establishment of the proposed outlying stations. It is now expected that by the end of 1957 at least two, and probably three, auxiliary stations will be set up at selected sites in Longmire (Mt. Rainier National Park), at Tumwater in the southern suburbs of Olympia, and near Neah Bay. To those interested in this project it will be desirable to mention some of the problems relevant to establishing such a network and to outline some of the specific results expected of the entire program once it gets fully under way.

One might believe that if a first-class seismograph station is desired it is only necessary to purchase a good seismograph, set it up, interpret the records, locate the earthquakes, and publish the results—all according to rules and practices laid down in seismological literature. A great and disappointing difficulty arises, however, from the fact that these hypothetical rules are something of a "will o' the wisp." While seismological textbooks thoroughly treat the broader aspect of seismometry and seismic wave transmission, seismological journals are replete with papers that supplement this basic information in an effort to place seismology on a practical operational basis. For this reason, any serious effort to establish a regional program of seismological investigation involves a high level type of research as regards both the operation of instruments (especially those of electromagnetic design now operating on the campus) and the interpretation of records, which here is meant to include interpretation in terms of local geologic structure. It is a truism that the accuracy with which an earthquake can be located depends entirely upon the accuracy with which the local crustal structure is known. The problems of locating earthquakes and delineating structure are inseparable.

When the writer took over the seismological work of the Geology Department in 1953, the first problem to arise was an instrumental one, resulting from the fact that the campus station rests on several hundreds of feet (possibly a thousand) of glacial till. Continual seismic vibrations in the underlying basement rock (so-called microseisms), which are generated mainly

by low-pressure areas over the oceans, are consequently amplified perhaps five times or more by the time they reach the seismographs at the surface. As a result, during the stormy winter season the recorded waves generally overlap each other to an extent that makes the seismograph record unreadable. The obvious solution is to temporarily reduce the sensitivity of the instrument to the point where the records are again decipherable. While the records of weak shocks will in any case be masked by this so-called background activity, a reduction in sensitivity means that a strong earthquake can still be well registered. On electromagnetic seismographs, such as the Sprengnether now operating at the campus station, this is best accomplished by changing the three resistances normally placed in the seismometer-galvanometer circuit. The object of this circuit is to pass some of the current through a shunt (reducing that passing through the galvanometer) while at the same time preserving the original resistances external to the galvanometer and seismometer. This is necessary to preserve the damping characteristics of these two units.

While an infinite variety of response patterns are possible with different combinations of seismometers and galvanometers, an effort is made to match the two units so as to produce a standard type of instrumental response to earthquake vibrations. Practically all the literature on seismometer theory happily assumes that this state of affairs has been realized and goes on to discuss what reductions in sensitivity are feasible with different seismometer-galvanometer combinations. In many cases, however, perhaps the great majority of cases, it is impractical for manufacturers to produce matched seismometer-galvanometer units, and even if they did, the performance characteristics are still subject to change.

The problem of combining unmatched seismometer and galvanometer units was attacked from both the theoretical and experimental angles and a solution reached which now makes it possible to make any desired step reduction or increase in sensitivity by simply turning a dial that switches in any one of six or more circuits. This represents an extension of what are generally considered classical treatises on this particular phase of seismometry. It represents not only the solution of a common seismograph station problem that will insure better seismograph records but eliminates perhaps the greatest bottleneck in the problem of utilizing electromagnetic equipment for measuring the amplitudes of ground vibrations. In studies of earthquake energy and in measuring the responses of different types of soils and rocks to earthquake vibrations, the accurate calibration of seismographs and the maintenance of adequate sensitivity controls are of paramount importance. It is noteworthy that seismologists in the past have always avoided galvanometric seismographs where quantitative results were desired, and have employed, instead, seismographs that registered directly (through various types of lever magnification) the motion of the seismometer pendulum itself. In the electromagnetic or induction type of seismograph the motion of the seismograph pendulum generates a current which is then recorded by a galvanometer. This involves two oscillating systems and produces a problem much more involved than that found in direct recording systems. An article on this sensitivity-control feature appears in the August number of the *Transactions of the American Geophysical Union* under the title, "Sensitivity Controls on Galitzin-Type Seismographs."

The next important problem to come under investigation concerns the location of earthquakes in the Puget Sound area. As previously indicated, this requires some knowledge of local crustal structure and of seismic wave speeds at different depths. One could assume that the same general type of crustal layering existed here as in adjacent areas, but this had to be proved or disproved. It is desirable to digress here for a moment to say that gravity surveys indicate that in the lower half of Puget Sound there exists one of the most abnormal features of crustal structure found anywhere in the United States. The greatest gravity anomalies and the sharpest gradients are found in this area. It is therefore not surprising that for years American and foreign geophysicists have been looking forward to seismic investigations of any kind that might shed more light on this obviously outstanding but little understood structural feature. In most areas information concerning local structure and seismic wave velocities is obtained from controlled explosions, by using methods developed in exploration geophysics but on a larger scale, especially with reference to the size of explosion required. But to-date no conclusive results have been obtained in the Puget Sound area, although one group of geophysicists working out of Washington, D. C., did carry on some work of a reconnaissance nature a few years ago.

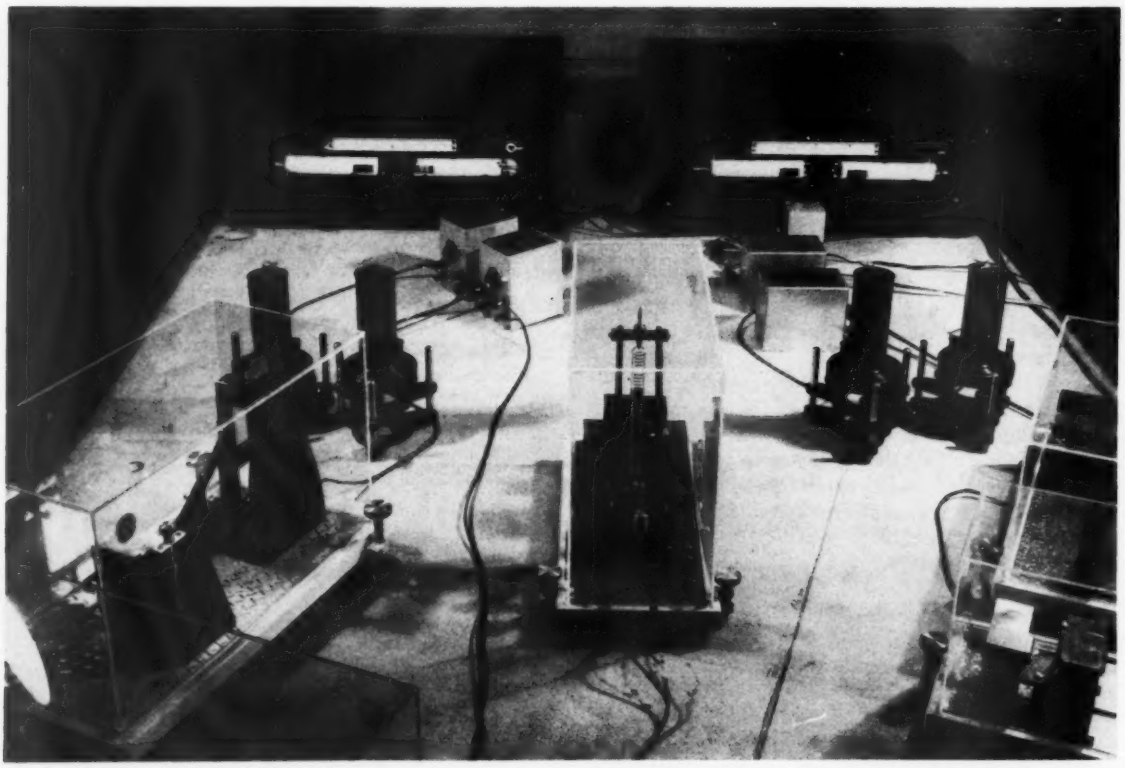
To attempt a solution of this problem on the basis of earthquake data alone would seem rather hopeless were it not for the fact that some very encouraging results based on a new approach have been recently obtained. Before elaborating on this research let it first be said that any effort in this direction would have been utterly hopeless were it not for the fact that the Canadian Department of Mines and Technical Survey established three first-class seismological stations in British Columbia that began operating in August, 1951, and have remained in operation since. Data from these stations (Victoria, Alberni, and near

Vancouver) and from the University of Washington made it possible to explore the situation at least to the extent of learning whether or not any acceptable results could be obtained by assuming certain typical structures and wave speeds found elsewhere on the west coast. We are indebted to Dr. John H. Hodgson, Director of the Canadian Seismological Service (Ottawa) and to Mr. W. G. Milne and Mr. R. W. H. White of the Astrophysical Observatory at Royal Oak, B. C., for furnishing the results of their observations on local shocks and cooperating in the project in other helpful ways. These seismologists had previously conducted some research along the same line in determining, through controlled explosions, that the speed of compressional waves in the shallowest layer of basement rock on Vancouver Island was 6.39 km per second.

Much time was spent in efforts to correlate the observed earthquake data with various "typical" crustal structures and wave speeds, but the results were inconclusive. It was then decided to simplify the problem by making certain assumptions which, although untenable from a strictly theoretical viewpoint, would provide what was considered at least a crude approximation of bona fide travel-time curves. It was felt that something would be gained if the earthquake foci thus located presented any sort of reasonable pattern. This effort resulted in a happy surprise when 30 earthquake foci were located and the results studied in the light of essential requirements. A consistency in the focal depths obtained, and in the distribution (with depth) of the several wave velocities used gave every indication that acceptable provisional results were being obtained.

This new technique for locating earthquake foci involves the following factors:

1) The assumptions pertain primarily to light shocks, many of which are not felt.
2) From various sources and studies it was concluded that three layers of basement rock having three distinct velocities exist in the Puget Sound area, namely, 5.8, 6.4, and 7.0 km per second. The higher velocity layers would normally be found beneath the lower velocity layers. One or more of the layers could be missing entirely. No layer thicknesses were assumed.



View of the seismograph pier in Johnson Hall, showing several seismometers in the foreground, recording boxes in the background, and four galvanometers and sensitivity-control units in the middle distance.

3) It was assumed that the first wave to arrive at a station travels over most of its path through the layer in which the shock originated. Ordinarily the last part of the path to the station would be through one or more overlying slower speed layers, but, for the purpose of constructing simplified travel-time curves, it was decided to ignore the existence of such overlying layers. It was assumed, instead, that the focus-to-station path is a straight line and that the over-all speed is the same as that in the layer in which the shock originated. It was also assumed that the travel times in both instances would not be too widely divergent to produce acceptable provisional results.

Without going any deeper into the technicalities of the problem, it will suffice here to say, first, that hypothetical travel-time curves based on the above assumptions were prepared for all three velocities and the data applied to them to learn what velocities, what depths, and what locations would fit the data best. In all cases it was possible to obtain excellent arc intersection once the right epicentral distances and depths were determined from the travel-time curves. Each solution indicated not only a specific focal depth but also the speed of the compressional wave at that depth. The test for consistency in the results lay in the requirement that the higher velocities always had to be found at greater depths than the lower velocities in the same general area; and this was found to be true. The epicenters also agreed well with epicenters located from descriptive reports in the few cases where shocks were rather widely felt.

One may legitimately conclude that, once enough earthquakes are recorded and the records analyzed, it should be possible to delineate the discontinuities separating these layers and obtain a fairly accurate picture of the obviously complex crustal structure in the Puget Sound area. The only outstanding feature which appears well confirmed at this time is a pocket or basin of slow speed (5.8 km per second) rock reaching a depth of some 30 km in the San Juan Island region and becoming shallower to the south. This particular feature ends rather abruptly just west of Victoria and in the foothills of the Cascade Mountains. This basin is three or four times the depth of comparable rocks found elsewhere in so-called normal continental structure. It would appear that all of the crustal rocks in this area extend to approximately three times the depths found in normal crustal structures.

Geologists in and out of the Department have found these rather limited and provisional results acceptably consistent with their broad concepts of crustal structure in this area and a similar consistency is found in efforts to correlate them with the gravity results obtained by J. W. Jones in 1952.* Where gravity anomalies indicate the probable existence of deep-seated faults of major extent, the seismological results tend to confirm this concept.

One may conclude that there is now every reason to believe that adequate earthquake observations extended over a period of years will gradually clarify the dim picture we now have of crustal structure in the Puget Sound area and at the same time provide material that will eventually perfect earthquake-locating techniques in this area. Needless to say, the establishment of the three auxiliary stations now planned will accelerate the program immeasurably and bring into effective use the data from many earthquakes in the southern Puget Sound region that are too weak to be registered at Canadian stations. This network will be equally important in the study of Canadian shocks in furnishing much desired data at certain critical epicentral distances which are now outside the reach of the Canadian stations. The project provides a splendid illustration of how seismological networks on both sides of the border work to the mutual advantage of each country.

Another seismological project on the campus concerns the publication of research material on "Earthquake Intensity and Related Ground Motion." This is the title of a booklet published by the University of Washington Press in 1954. Most of the analytical work was done while the writer was still on the staff of the U. S. Coast and Geodetic Survey in Washington, D. C. It represents one of the first serious attempts to analyze the great mass of earthquake intensity reports and strong motion seismograph records accumulated by that bureau over a 30-year period. Mathematical relationships were developed between various kinds of seismological data, including earthquake intensity (Modified Mercalli Intensity Scale of 1931), ground accelerations, velocities, displacements and periods, and epicentral distances. These results are of primary interest to structural and foundation engineers responsible for the safety of structures in earthquake areas, but they are also of considerable interest in the broad field of geophysics.

One of the most important results of this analysis is the clear demonstration that different types of soils and rock respond in widely different degrees to earthquake vibrations which are transmitted primarily through the underlying basement rock. It now appears that in the case of both earthquake and explosion vibrations soft alluvium may vibrate through 25 or 30 times the amplitudes experienced on outcrops of basement rock, all other conditions being the same. Recent reconsideration of this broad fact has made it necessary for the California Institute

* See *The Trend in Engineering*, Vol. 4, No. 3 (July, 1952).

of Technology to revise its formula for measuring the magnitude or energy of earthquakes, the inadequacy in the original formula being due to the fact that the so-called "foundation factors" at various seismological stations were not adequately taken into account.

Engineering interest in the scientific measurement of this foundation factor has reached a point where U.C.L.A. now has a project under way to further study the problem. In this regard the writer feels that it would be worth the effort to learn whether or not microseismic waves, which are always present in the basement rocks, might be used to determine these factors, by measuring the extent of their amplification when transmitted through various types of soils and rocks. If this method is found feasible, foundation factors could then be determined by operating sensitive seismographs for an hour or so at a site where the factor was known, and simultaneously at any other site where it was desired. This was, in fact, one of the reasons why, as previously stated, considerable effort has been put into the problem of utilizing electromagnetic seismographs for making reliable quantitative ground-vibration measurements. Although this is all a very highly specialized subject, wide interest in it and in related probems has been demonstrated by an unexpectedly early sell-out of the first printing of the booklet previously mentioned. Additional copies have been printed to take care of a small but apparently continuing demand.

Aside from these special projects that are under way, the routine work of the seismograph station itself constitutes one phase of a broad international program of research which has for its first objective the early but provisional location of all earthquakes strong enough to be of significance. This benefits not only the scientifically minded public, but it means that seismologists everywhere are enabled to make more accurate and productive analyses of their records than would otherwise be possible. This vastly improves knowledge of the velocities and paths of seismic waves transmitted through the earth, thereby improving the ultimate accuracy of earthquake locations (especially where epicenters are in isolated areas) and our knowledge of the interior structure of the earth. Seismology furnishes the best information we have today on deep earth structure.

To accomplish these objectives all first-class stations in the United States and in foreign countries wire significant seismograph recordings immediately to the U. S. Coast and Geodetic Survey in Washington, D. C., which is the Federal agency charged with earthquake investigation. Within a few days after the data have been processed, they receive the provisional locations, depths, and origin times of of practically every significant earthquake registered. A similar program is conducted on a broad international scale through the headquarters of the International Seismological Association in Strasbourg, France. All stations publish their results periodically, generally in annual Seismological Bulletins. The results of the international program, including selected basic data from all stations and final epicenter locations, are published in the *International Seismological Summary* at Cambridge University, England.

In concluding, the Executive Officer of the Geology Department, Professor H. A. Coombs, and the writer both wish to gratefully acknowledge the assistance rendered the seismological program by the Engineering Experiment Station. In furnishing shop facilities not available in the Geology Department and in many other ways this unit has done much to help make our seismological service, although still very limited in scope, comparable with the best.

The Formulation of Problems in Research

(Continued from page 1)

relatively large "safety" or "ignorance" factors applied to all engineering operations.

Problems of applied physics and engineering must be formulated in four different sets of terms, as follows:

In descriptive terms (semantic formulation)
In analytical terms (model formulation or hypothesis)
In operational terms (experimental formulation)
In statistical terms (formulation of relation between model and reality in terms of operation)

In formulating problems of this type the engineer or industrial research worker is usually too much concerned with the immediate concrete objective to pay attention to the theoretical principles of research methodology. Thus he is hindered in developing the most effective approach to the formulation and solution of his problem, particularly since these methods are generally not the most obvious or the most direct.

The underdeveloped faculty to abstract of many engineers, who are trained in concrete rather than abstract thinking, may be a definite handicap in engineering research, where the complex effects of a number of factors must be evaluated. There is then a danger of what Alfred North Whitehead calls the "fallacy of misplaced concreteness," in trying to describe a phenomenon in terms of an insufficiently known number of relevant factors. When reasoning deductively about a complex phenomenon, a number of factors are usually left out either because of negligence or because of ignorance. The conclusions reached in those cases must therefore be fallacious.

The fallacy of misplaced concreteness is very common in the form of arguments involving "other things being equal." In general, it may be said that all arguments involving such notions are probably fallacious except when the universe of discourse is arbitrarily limited by abstraction, as in mathematics and theoretical science. There is never any reason to suppose that until the conclusions have been well tested, such reasoning can be safely applied to the complex reality of engineering problems.

Another aspect of misplaced concreteness is the acceptance of one particular aspect of a phenomenon as the complete picture. Related to this is the lack of intuitive realization that by looking from one single point at a single time only a partial picture can be obtained, and that this picture will become complete only by coordinating observations from all possible view points and distances at various times. It is not sufficient to see a phenomenon sharply (that is, closely); it is also necesary to see it as a whole. It is always useful to realize that the closer we look, the more detail we see on a gradually decreasing area until, in the limiting case, we see "everything of nothing."

Thus in order to obtain an adequate picture of a phenomenon, it is not only necessary to vary the point of view, but also the distance or focus, so as to coordinate the detail with the whole. Thus, when the engineer considers the material as an aggregate of particles, it is only because from a distance, certain phenomena remain inexplicable or invisible. . . .

Three general principles underlie the formulation of a problem in terms of an experiment to answer a question of fact:

1. The meaning of the question must be reducible ultimately to data obtained from "pointer reading" so that conditions are given specifying the exact manner in which pertinent observations are to be made;
2. Conditions must be given to make a response to the question possible on the basis of a finite set of observations (small sample analysis)
3. Conditions must be given which ensure an indefinite approximation to the answer to the question if the number of experiments is increased ("stochastic limit")

Observation in scientific investigation, however, never designates a purely passive attitude on the part of the observer. The purpose of the observer determines to a large extent what will be observed in any given situation, and particularly which attributes are neglected as inessential . . . The narrowness of the observer's focal point of attention tends to exclude from observation everything not directly connected with the immediate purpose.

Hence, effectiveness of observation depends upon the observer's knowledge of the problem, since observation is not always a simple process of measuring or enumeration; it involves observation of causation when the phenomenon is not directly observed, but only the effect which it produced. Since the significance of research depends on the observation methods, the effectiveness of these methods and the effectiveness of the observer himself are primary considerations in formulating research problems.

Knowledge is obtained directly by experience or observation, or indirectly by inference or deductive reasoning from results of direct observation. Either direct experience or logical arguments are made to justify a certain degree of rational belief about all sorts of conclusions assumed to be significant with regard to the problem considered. The purpose of these attempts is to organize, for subsequent application, the knowledge thus derived, preferably in the form of mathematically formulated relations between significant variables.

Mathematical symbolism is intended to free a presentation from looseness, duplicity and redundancy. That such symbolism implies precision or guarantees accuracy of statement is a delusion from which engineers in particular frequently suffer. No matter how precise the statement appears, a theoretical deduction is no more precise and accurate than the basic assumptions, which are always inferential generalizations from experience. The more complex the problem and the larger the number of operations involved in its solution, the wider the variability of results to be expected, and the more important the application of statistical theory in its formulation. . . .

Statistical methods help the experimenter to acquire knowledge about a fundamental but not clearly evident system of causes which underlies the experimental or observational data and which might produce similar data in the future. Thus the interest is less in the characteristics of the statistical "population" from which the data are drawn.

If a number of factors affect the phenomenon under investigation, the statistical approach will aid in determining how to combine these factors. Two types of experimenter exist in general: the man who sticks to the single variable and the "changer of everything at once." . . . The man who in setting up his experiment changes everything at once may in fact not know to which class he belongs. He may be even less aware of the methods at his disposal to perform a valid experiment in spite of his changing so many variables.

On the other hand, there is a deeply ingrained conviction among the more scientifically-minded engineers that unless you vary but one variable, you can never hope to attain significant results. This conviction leads to the setting up of extremely specialized experimental procedures and to an unnecessary multiplication of tests. As always, the best procedure lies in the middle.

Conclusion

An ideal procedure for problem formulation could thus be described as follows: a formal theory is developed by intuition, formal logic or deduction (logical inference) from certain presuppositions assumed to be true on the basis of prior knowledge. This theory embodies the concept of observation, and such statistical concepts as distribution function, randomness and numerical probability.

Pertinent questions are then formulated that can be translated into groups of alternative statistical hypotheses concerning the observations of the selected variables at any given time. These alternative statistical hypotheses are "tested" by deducing from the observations associated with them a judgment concerning the measure of probability of the truth of either hypothesis. Thus the decision to accept or reject the original theory is not based on consideration of "truth" or logical consistency, but essentially on considerations of probability.

This latter distinction is the principal difference between so-called "formal" aspects of science and the "empirical" or "nonformal" aspects of science: the criterion of acceptance or rejection in formal science, such as mathematics, is based on logical consistency, whereas in empirical science, the criterion is essentially one of probability. The rejected alternative is not logically inconsistent and therefore "false," but only improbable with reference to the assumptions made and the experimental evidence considered. Thus the absolute "truth" criterion is replaced by the relative probability criterion which must be supported by a considerable amount of intuition on the part of the experimenter to fill the gap where exact methods are lacking. It is the same intuition, born of a familiarity with all aspects of the problem that can only be acquired through concentration and effort, without which no research problem can be effectively formulated.*

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* Professor Freudenthal supplemented the foregoing exposition of the problem by extensive quotations from Poincare's *Science and Hypothesis.*

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

CHOU, TAH-LOW, "Transistor Class C Oscillator Design." M.S. in Electrical Engineering, 1956.

A germanium junction transistor Class C oscillator was designed by directly adopting the well-known vacuum-tube circuit design techniques. The semi-graphical method for vacuum-tube Class C amplifier analysis has been employed for the transistor oscillator design. The experimental results prove that this new approach for the transistor circuit design is adequate and applicable.

Two GE ZJ3-1 germanium PNP junction transistor Class C oscillators were designed and tested. Over-all efficiencies as high as 83.6% were obtained for the oscillators with 6.08 mw of output power.

With this new approach, the extensive knowledge of vacuum-tube circuit analysis will be very useful for transistor circuit study. As a consequence, one handicap of transistor usage, the lack of background art in design of devices and circuits employing transistors, may be overcome.

DASU, SITA, B. V., "The Investigation of Interference from Flexible Single- and Double-Sheath Cables," M.S., in Electrical Engineering, 1956.

An analytical approach to the problem of interference from flexible coaxial and triaxial transmission lines is presented in this thesis.

The first part deals especially with the coaxial cable (single-sheath), the sheath of which is grounded at both the sending and receiving ends. It is theorized that the interfering current is a result of the nonuniform current distribution in a braided sheath. The flux linkages inside and outside of a cable where interference exists are explained, and an equation is derived for the interfering current with the help of simple transmission-line equations. Since the first part is presented partly to verify the procedure of approach to the problem at hand, the interfering current is calculated at different points along the length of the cable using the equation derived, and is plotted against the length of the cable. An experiment was set up to measure the interfering current along the cable and a curve was drawn to represent the current along the length of the cable. Close correlation is seen between computed and experimental curves for all frequencies. Then, by examining the equation for interfering current, some suggestions are made to reduce the interference. A special study was made to find out the effect of the length of the cable on the interference. From sample computations, it was found that the grounding of the sheath at intervals of approximately $0.15\lambda_0$ reduces the interference to a large extent. Though interference increases for intervals greater or less than $0.15\lambda_0$ it is still relatively low for any length up to $0.3\lambda_0$.

In a multiple-sheathed cable, which is discussed in Part II, the interference should be less, since the installation of one or more sheaths over the first sheath of a coaxial cable tends to smooth out effects of variations in current density. A study of a flexible triaxial transmission line was accordingly made. The thesis deals with only two phases of the problem:

1) grounding both the sheaths at the sending end only and tying the two sheaths together at the receiving end and leaving them ungrounded;
2) grounding both the sheaths at both ends.

The flux linkages for the double-sheath cable are explained and equations are derived for the interfering current in both the cases mentioned above, following the method of Part I.

A principal objective of Part II was to find the effect of changing a_2—the ratio of the velocity of propagation in free space to the velocity between the two sheaths. At high values of a_2, the interference proved to be minimum except for a half-wavelength line (wavelength between the sheaths).

Also the interference is reduced when a_1 (the ratio of the velocity of propagation in free space to the velocity inside the cable) is equal to a_3 (the ratio of the velocity of propagation in free space to the velocity outside the cable).

The interference, then, will be reduced if

1) a_2 is made large by using insulating material of high dielectric constant between the two sheaths,
2) a_1 and a_3 are made much smaller than a_2 by using proper insulating materials inside the cable and outside the cable,
3) the length of the line is less than $0.3\lambda_0$ with a minimum interference at a length of approximately $0.15\lambda_0$.

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